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Devlopment of a methodology based on Digital mock up towards improving Digital Twin Concept for complex system: Design, migration and maintenance

PEPR ENSEMBLE – PC2 PILOT

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Who am I ?

Clarissa Gregory, 2nd PhD student

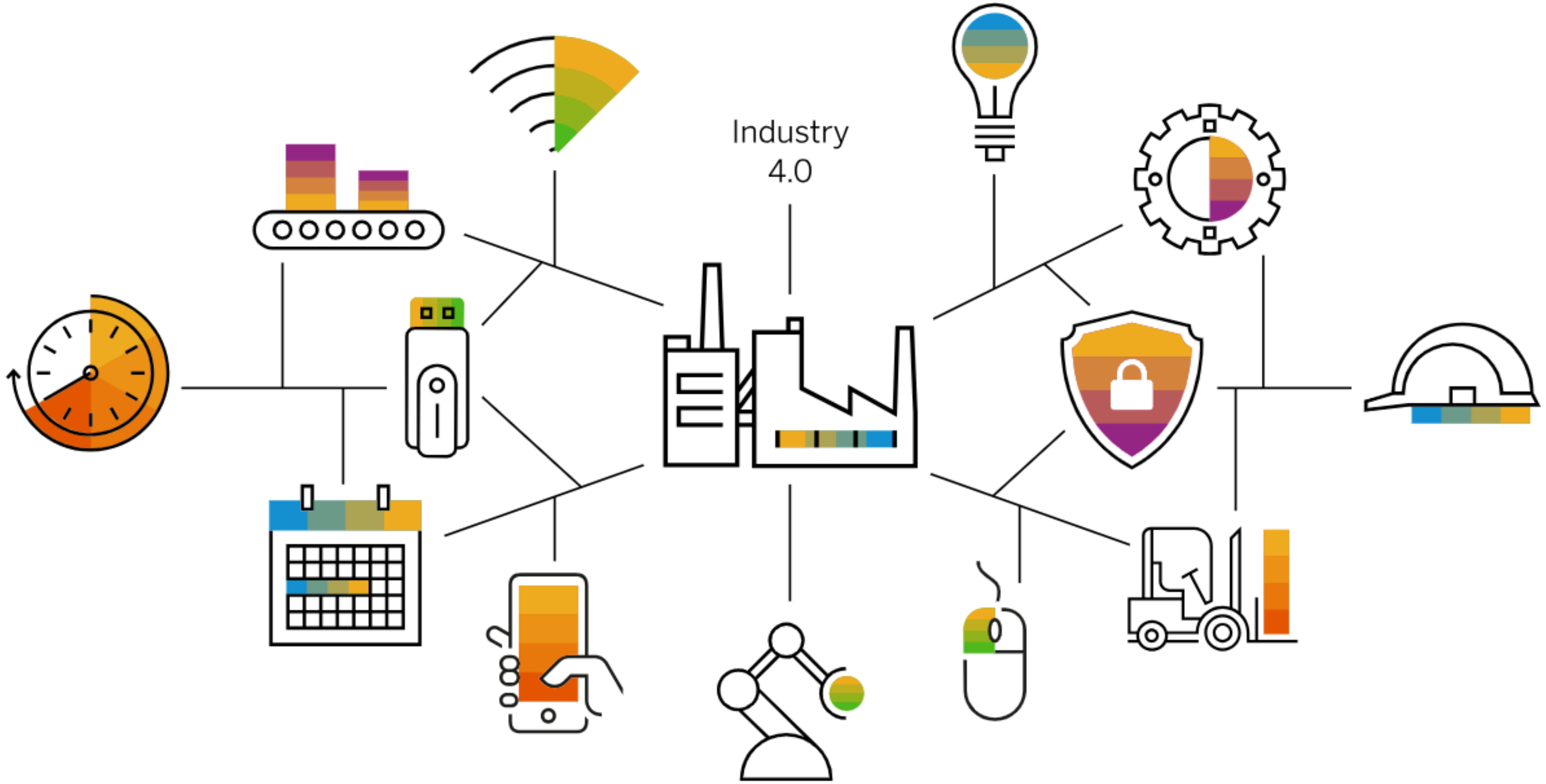
Supervisors
Vincent CHAPURLAT
Souad RABAH-CHANIOUR

PhD Student since 2nd October 2023

- Curriculum:
- 2017-2019 : Prépa PTSI-PT in Voiron (38)
- 2019-2023 : IMT Mines Alès, Mecatronic and Industrial science department
- 2021-2023 : Double degree program Keio University Tokyo
- 2023: PhD student in Laboratoty for the science of Risks, CERIS team ISOAR
- Development of a methodology based on Digital mock up towards improving Digital Twin Concept for complex systems: Design, migration and maintenance
- PePR eNSEMBLE – PC2 PILOT since December 2024 as « Accompagnement »

Agenda

1. Industry 4.0 and key technologies



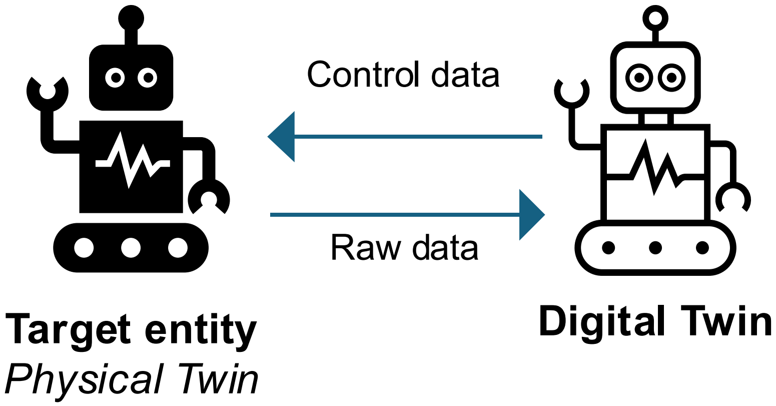
Source: https://www.sap.com/france/products/scm/industry-4-0/what-is-industry-4-0.html

Industry 4.0

Traditional industry combined with **internet technologies** and apparition of cyberphysical systems.

(Ramdasi et al, 2018)

2. Introduction, motivation and thesis problem statement



Digital Twin (DT) ⇔ **Virtual** and **accurate** image of a target entity to answer a use with an accurate synchronisation rate (ISO 30173)

DT usages: control, optimisation, prediction, maintenance and training

Fundamental technology of Industry 4.0 (Gartner 2023)

Complex systems = Complex representations
Recent standards [1], [2]

Engineering processes are **time consuming** and **expensive**

Research of a **method** for **Digital Twin engineering** based on **Systems Engineering theory**

[1] : ISO 23247. 2021, " ISO 23247:2021 Automation Systems and Integration — Digital Twin Framework for Manufacturing ." International Organization for Standardization, Geneva, Switzerland, 2021.
[2] : ISO/IEC 30173:2023, "ISO/IEC 301733:2023 - Digital twin - Concepts and terminology." International Organisation for Standardization, Geneva, Switzerland, 2023.

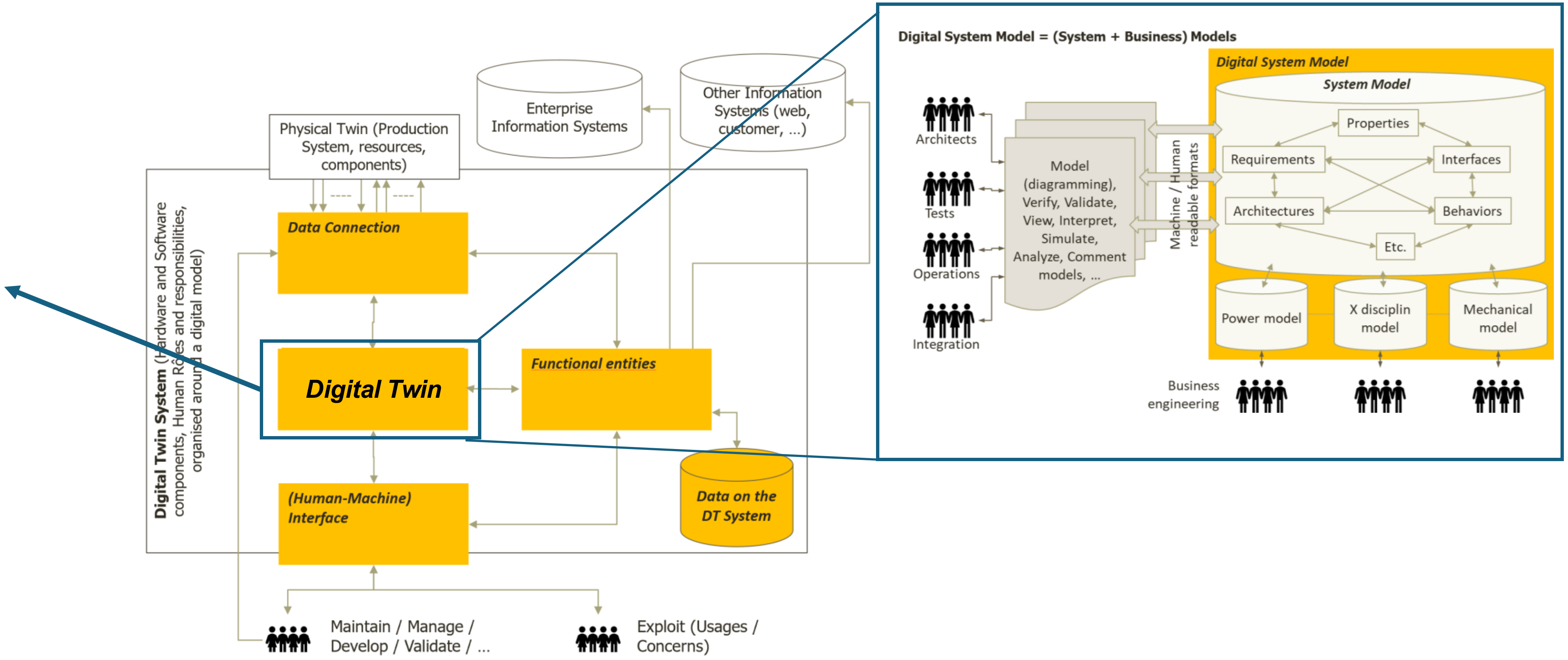
3. Theoretical background, state of the art in literature

3.1 The Digital Twin

2 ISO standards provide a Digital Twin definition and engineering framework elements
-ISO 23247:2021 *(manufacturing)*

-ISO 30173:2023

Digital Twin⇔ **Virtual** and **accurate** image of a specified system answering a specified use



Digital Twin System ISO30173:2023

3. Theoretical background, state of the art in literature

3.2 Systems engineering and model-based systems and software engineering

System: Arrangement of parts or elements that together exhibit a stated behaviour or meaning that the individual constituents do not. (ISO15288-2023 – Systems engineering)

Systems Engineering: Transdisciplinary and integrative approach to enable the successful realization, use and retirement of engineered systems using principles and concepts and scientific, technological and management methods. (ISO 15288:2023 – Systems engineering)

Model Based Systems and Software Engineering: Formalised application of modeling to support systems and software engineering. (ISO 24641 – 2023)

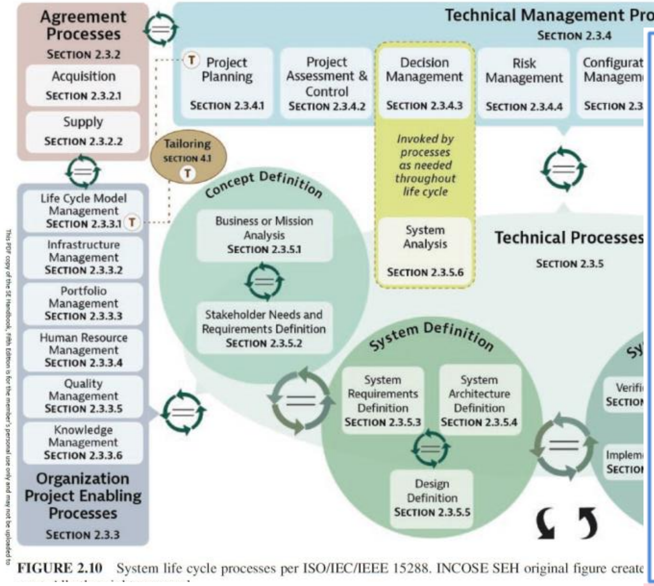
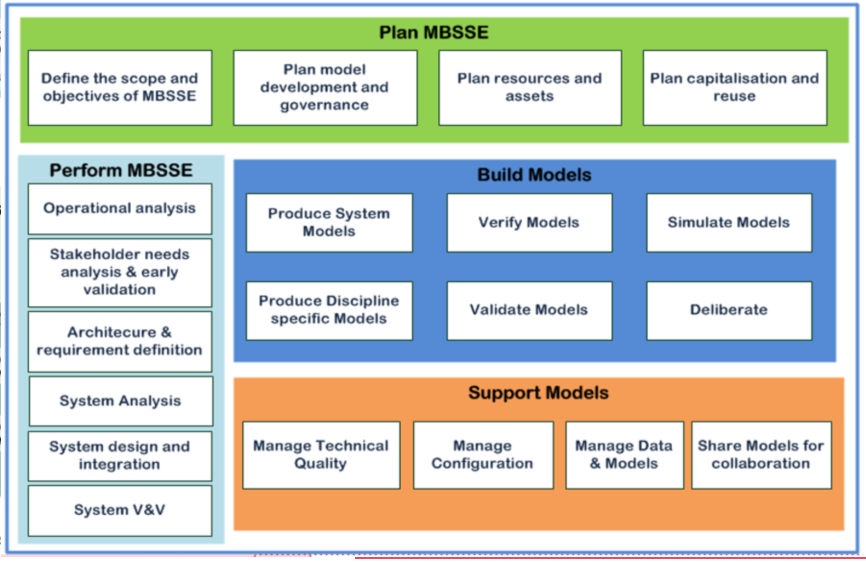


FIGURE 2.10 System life cycle processes per ISO/IEC/IEEE 15288. INCOSE SEH original figure create

Source: INCOSE Handbook, 5th edition, INCOSE



Source: ISO 24641:2023 : Model-Based Systems and Software Engineering

- ✓ Design methodology suitable for **complex problem solving** associated with **numerous requirements**
- ✓ **Modeling**: improved collaboration and information sharing
- ✓ **Numerous stakeholders**

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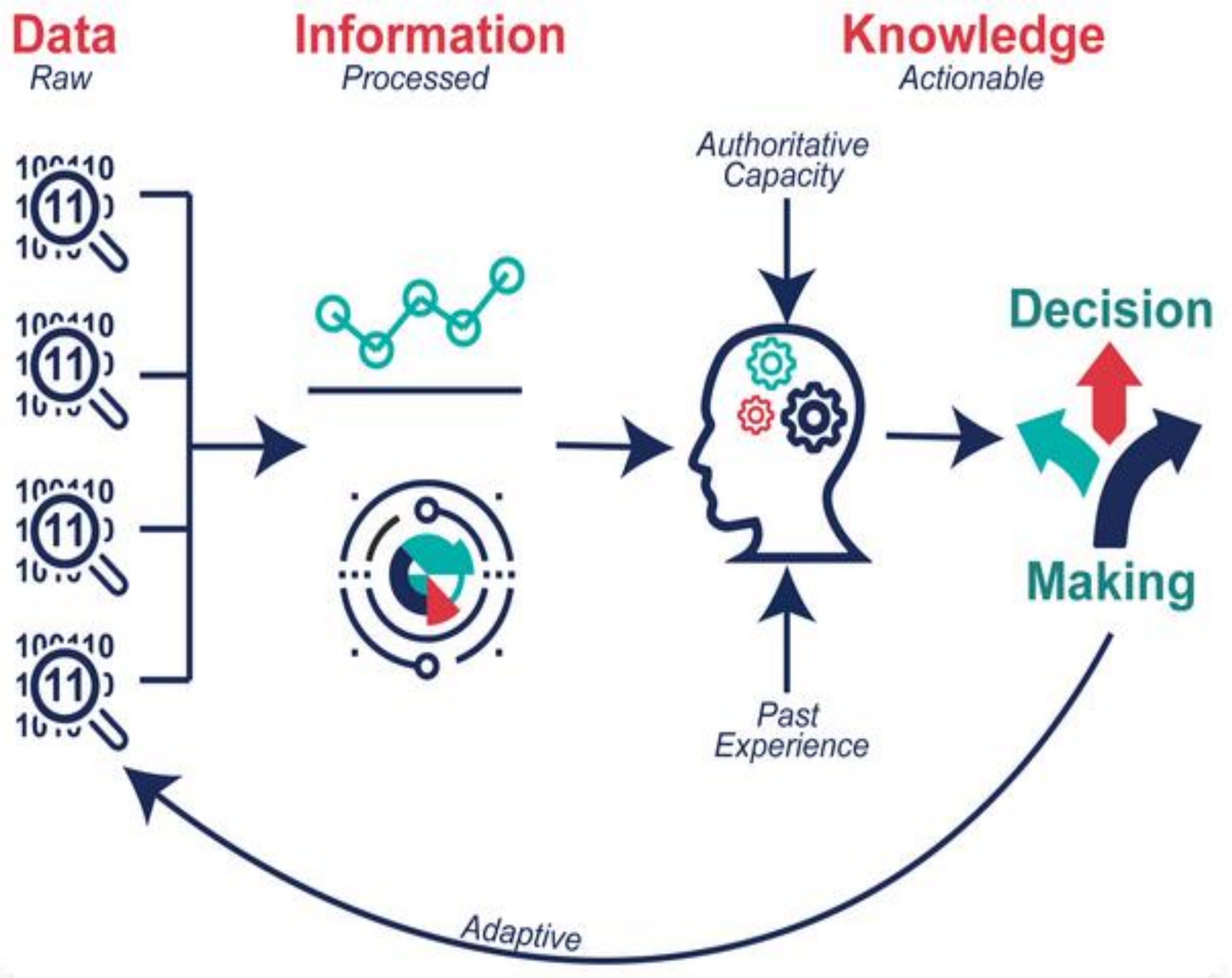
3. Theoretical background, state of the art in literature

3.3 Data, information and knowledge



Context Industry 4.0 (El Alaoui et al, 2022)

Item: any digital elements involved in the description and caracterisation of a system: pattern, operation data…

Data: item without context.

Information: contextualized item, with, resulting of a treatment or not.

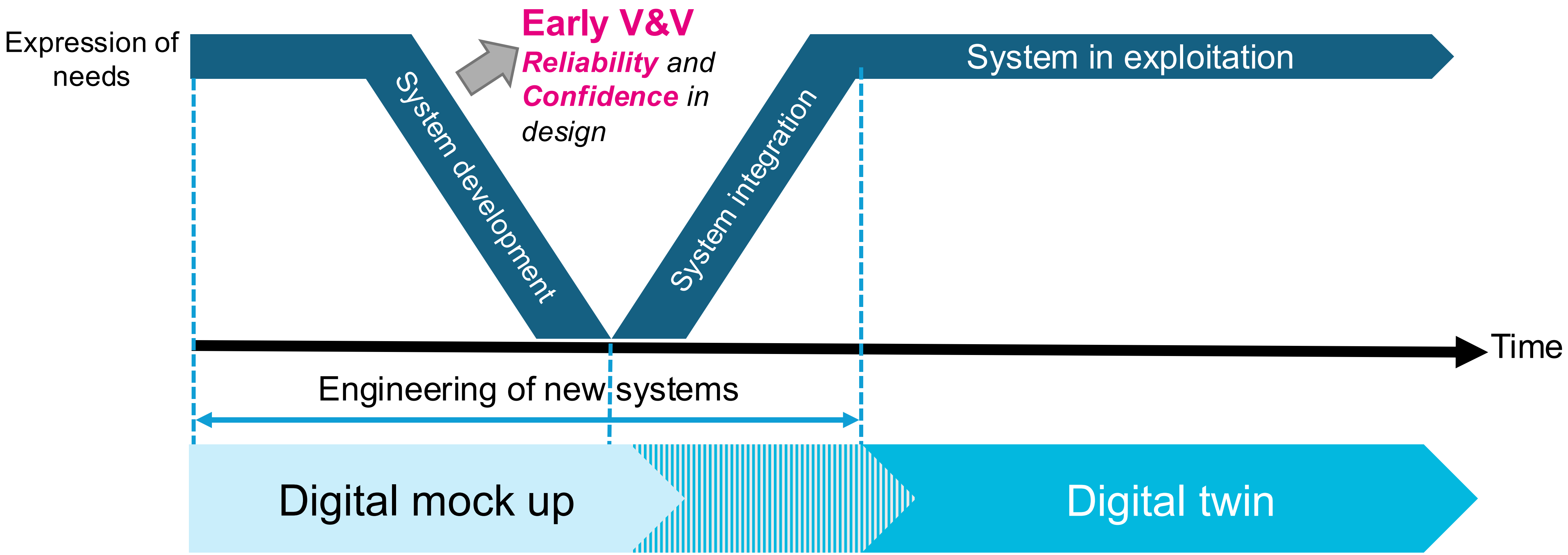
Knowledge: contextualized and interpreted item use for decision making and action.

Source: https://internetofwater.org/valuing-data/what-are-data-information-and-knowledge/

3. Theoretical background, state of the art in literature

3.4 The Digital Mock-up and the Digital Thread

Digital Thread = Gathering items across system life cycle (AIAA, 2023) ➔ Opportunity for Digital Twin Engineering (Semeraro et al, 2021)



Problematic: reuse of items generated during system life cycle for Digital Twins Systems engineering (Semeraro et al, 2021), (Liu et al, 2023), (Zhang et al, 2022), (Jiang et al, 2023)

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4. Problem statement

Digital Thread

Digital mock up → Digital twin

- Gathers and potentially federates items generated during the engineering of the target entity (Chapurlat and Nastov,2020)

Individual models: partial representation of the system under a parital and chosen point of view to support engineering choices

?

Need of accurate, federated and connected representation of the target entity

Need of confidence in the model
Early V&V process

Need of interoperable models to build a representation fitted to a use

Models' federation

How to federate heterogenous models ?

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4. Problem statement

Complex Systems Design

Numerous stakeholders

Numerous requirements

Numerous design items

Siloed working practices

Lack of interoperability

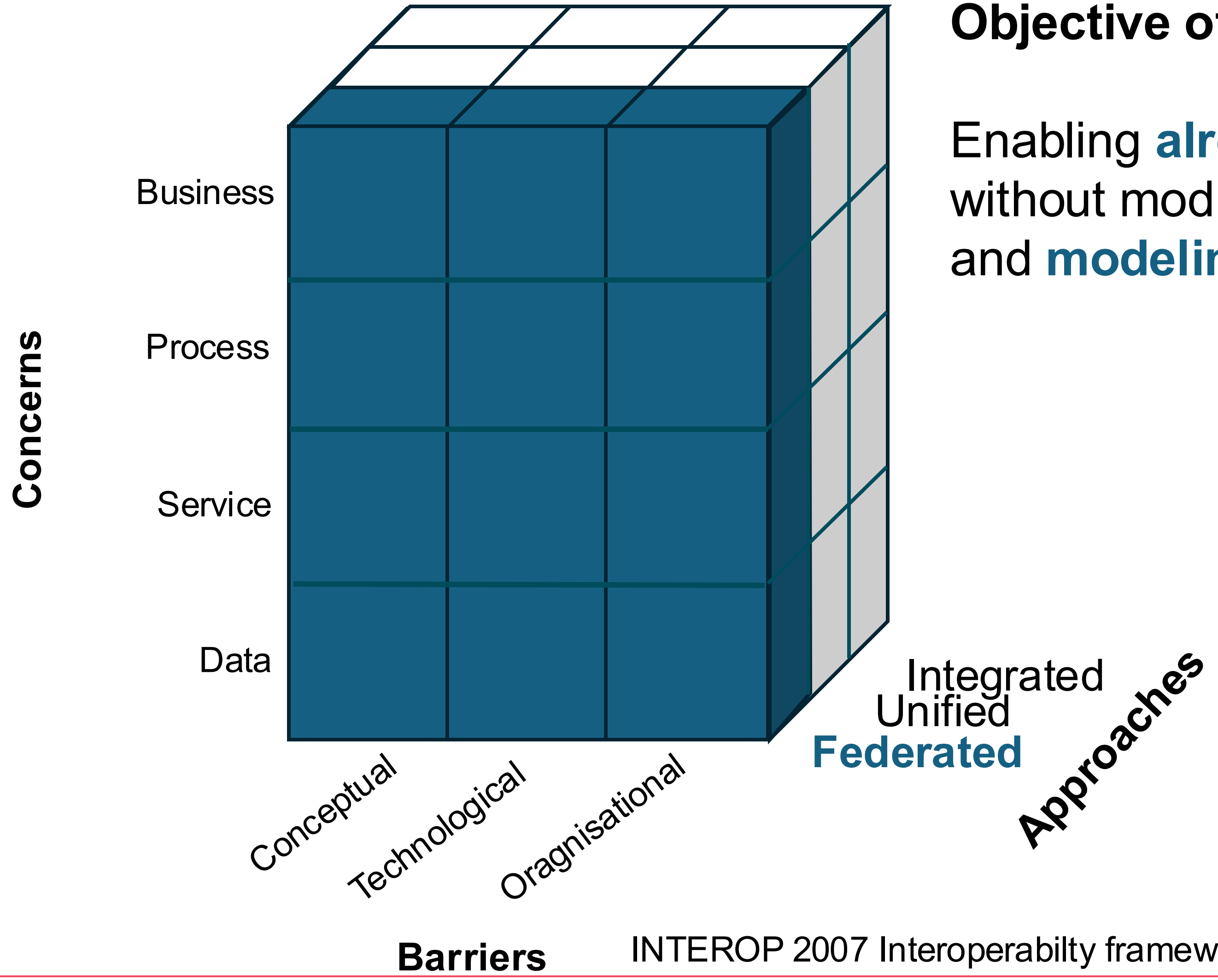
Reduced collaboration

Difficult design process

Proposition to the PC2 PILOT of **methodological approaches** to tackle **interoperability** and **collaboration problems** during engineering processes

5. Proposed approach: Federated interoperability

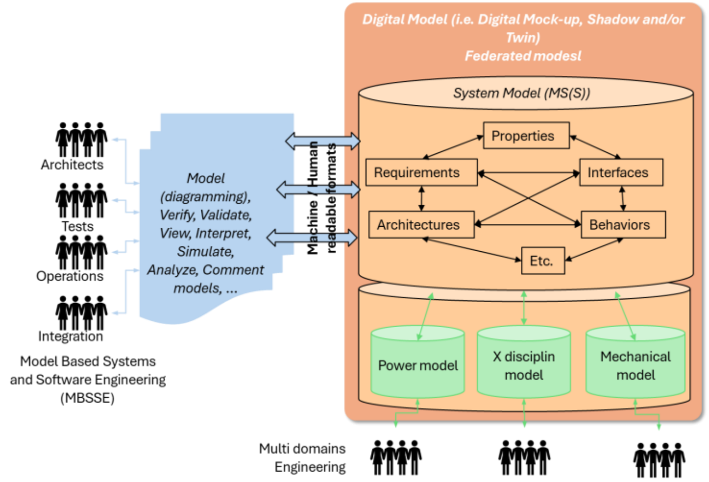
5.1 An interoperability framework



INTEROP 2007 Interoperabilty framework

Objective of model federation in this PhD research

Enabling **already existing distinct models** to work together without modifying them, i. e. **without sharing languages** and **modeling tools**



5. Proposed approach: Federated interoperability

5.3 Metamodel - A definition

Modeling Pyramid according to Object Management Group (OMG)

Level 3 – Meta meta model level

Conform to

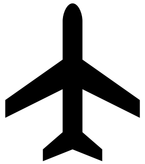
Level 2 – Metamodel level : specifies modeling language

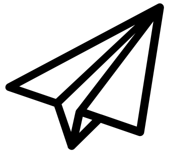
Concept 1

Concept 2

Concept 2

Conform to





Level 1 – Models of physical reality

Represented by

Level 0 – Physical reality

5. Proposed approach: Federated interoperability

5.2 State of the art

Federated interoperabilty

Metamodeling
Taylored modeling languages

Ex: xviDSML, Nastov, Chapurlat et al 2016

Formal approaches
Based on mathematically model transformation

Ex: Formal model transformation for **interoperability purposes**
Use of Hypergraphes, Labreche et al, 2023
Moretti, et al 2023
Model transformation **not necessarilly for interoperability purposes**
Use of higraphs, Aboutaleb et al, 2015
Wymore, 1996

Model encapsulation
Cosimulation of models, managing only inputs and outputs of model

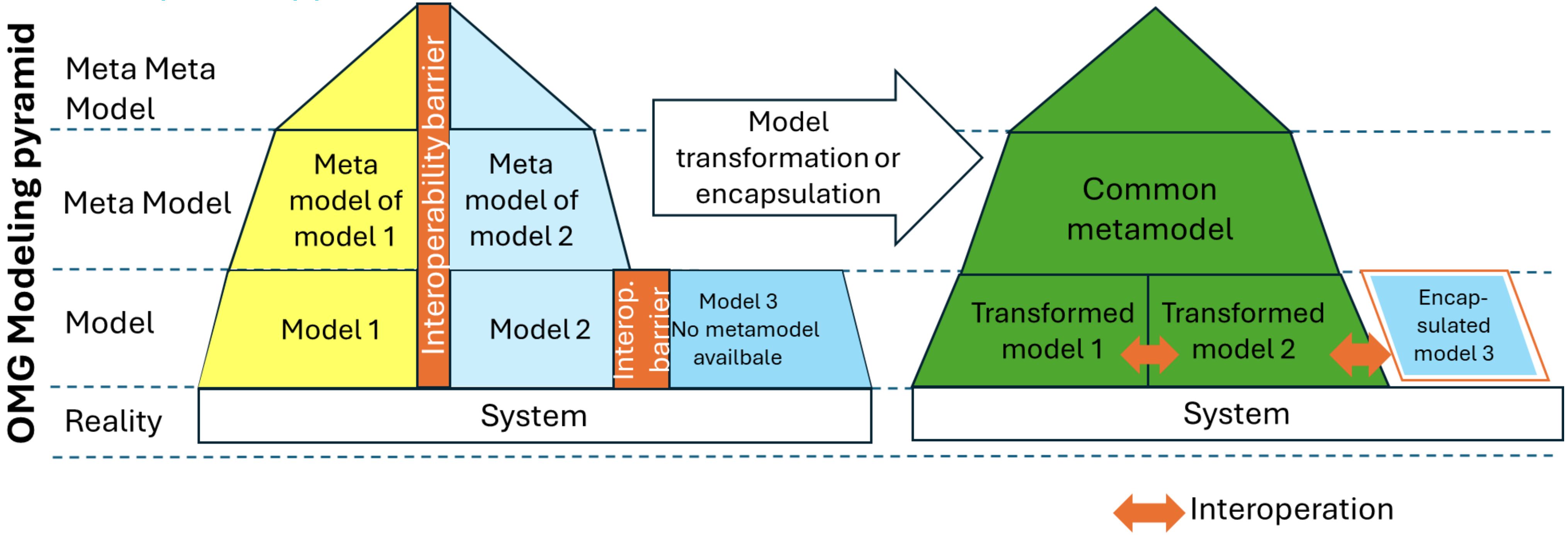
Ex: Functional Mock-up Interface FMI-FMU standards
HLA (High Level architecture), El Kassis et al, 2024

Search of universal modeling langage

Ex: Universal Entreprise Modeling Language (UEML)

5. Proposed approach: Federated interoperability

5.4 Proposed approach



Metamodel available:
Use of model transformation techniques
- ✓ General and formal approach
- × Requires metamodel
- × Modification of model properties

Metamodel not available:
Use of standards such as FMI/FMU (cosimulation) or HLA (federation)
- ✓ Confidentiality
- × Black box

Research of **formal approaches** based on **graphs theory**

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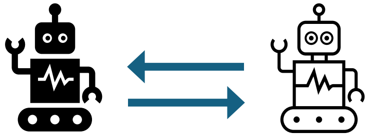
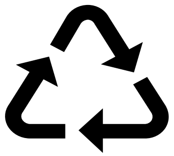
6. Conclusion – PhD within PC2 PILOT

Objectives of the PhD Project



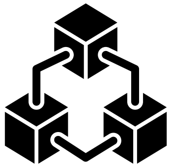
Digital twin engineering
Refined and synchronised representation



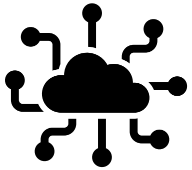
Digital Thread
Context of digital continuity

Research for methodologies for federated interoperability

Improved collaboration



Preservation of stakeholder’s practices



Collaboration with systems and software from the operational environment

Research for **formal approaches** to improve interoperability withing the **MBSE framework**

Thank you for your attention

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Research work:
Paper presented during 18th IFAC Symposium on Information Control Problems in Manufacturing, 28th – 30th August 2024
Model Based Systems Engineering applied to Digital Twin engineering: Why and How to ? (C. Gregory, R. Mbolamannamalala, S. Rabah and V. Chapurlat, 2024)

Congrès annuel de l'AFIS 2025, poster pour le séminaire doctoral : Digital Thread based federated interoperability approach for DT engineering, C. Gregory, S. Rabah, V. Chapurlat

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Logo Partenaire

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